A scientific approach to STEM education

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I. NSTC Committee on STEM education update
II. Research on STEM education

*based on the research of many people, some my group
(most talk examples from physics, but results general)

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The National Science and Technology Council Committee on STEM Education
(created Jan. 2011, by America Competes reauthorization)

Co-Chairs Carl Wieman OSTP
Subra Suresh NSF

Committee on STEM Education

(2010 America Competes Legislation)
Formed March 4, 2011

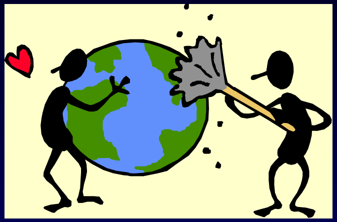
Federal STEM Inventory Task Force	Federal STEM Ed Strategic Plan Task Force
Finish– late Summer	Finish– ~January 2012
Detailed characterization of all federal STEM activities.	Develop a 5-year STEM Ed strategic plan .

NSTC STEM Inventory compared to ACC

Topic	Previous Inventory by Academic Competitiveness Council	Current Inventory by Committee on STEM Ed (anticipated late summer '11)
Definitions of units	Collected information on "programs". Different at each agency.	Common unit of analysis within and across all agencies.
Definition of STEM Education	Each agency defined STEM education differently.	Detailed consistent definition that captures only those efforts whose <u>primary</u> goals are STEM Ed.
Program Details	Only general information on goals, budget, range of objectives, and target audience.	More detailed information (objectives, services provided, products, who served, type of evaluations, $$$, …)
Total number	110	250-300
Total funding	ACC $3.6 billion	NSTC $ less (guess)

Why need better science & eng education?

•Scientifically literate public



Presidential priority

•Modern defense & economy built on S & T

Need **all** students to think about and use STEM more like scientists and engineers.

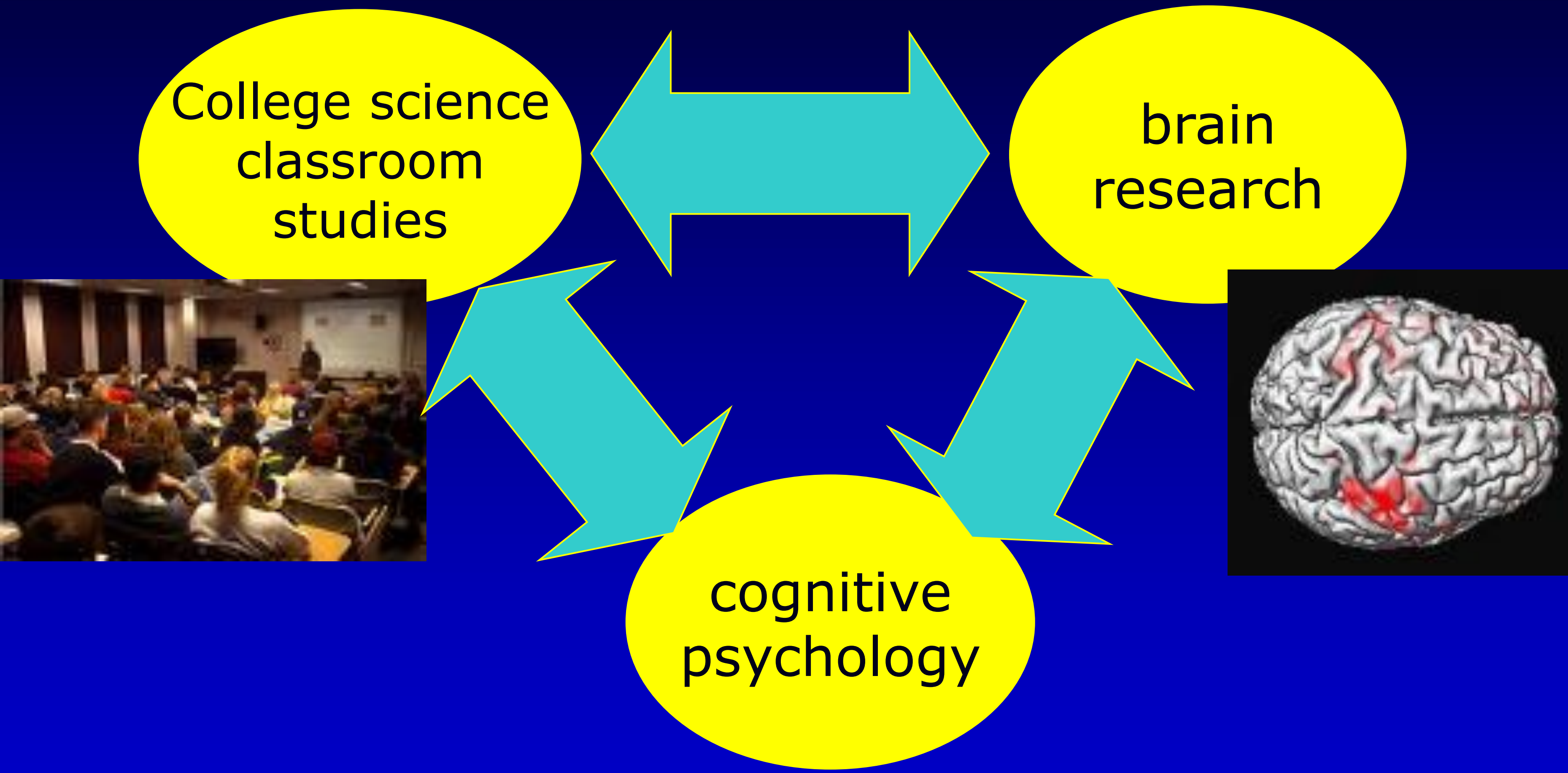
II. Science Education as a science

My Physics graduate students--
Why excellence in physics courses $\neq$ competence in physics research?
Two years in lab transforms?

approached as science problem,
look at research (past and future)

15 years later…

Major advances past 1-2 decades
Consistent picture ⇒ Achieving learning



Research on learning complex tasks
(e.g. expertise in math, science, …)

old view, current teaching

knowledge

soaks in, variable

new view brain plastic

transform via
suitable "exercise"

Ask not "What do I want to explain or show?",
but "What mental processes do I want to stimulate?"

Expert competence research*

historians, scientists, chess players, doctors,...

Expert competence =

- factual knowledge
- **Mental organizational framework** $\Rightarrow$ retrieval and application

or ?

patterns, associations, scientific concepts

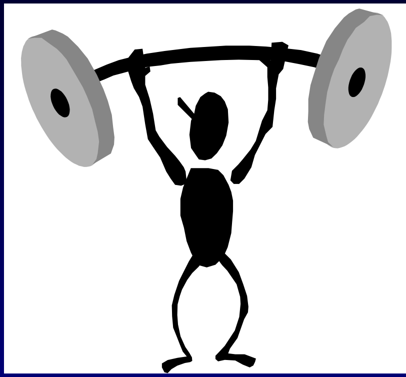
- **Ability to monitor own thinking and learning**

("Do I understand this? How can I check?")

New ways of thinking-- require MANY hours of intense practice. Change brain "wiring".
Brain develops with "exercise"

*Cambridge Handbook on Expertise and Expert Performance

Practicing expert-like thinking--



Challenging but doable tasks/questions

Intense explicit focus on expert-like thinking
- •concepts, mental models, and analogies
- •means to test when and how apply
- •recognizing relevant & irrelevant information
- •self-checking, reflection, and correction

teacher--effective feedback & guidance, motivates

knowledge, but embedded in context and process

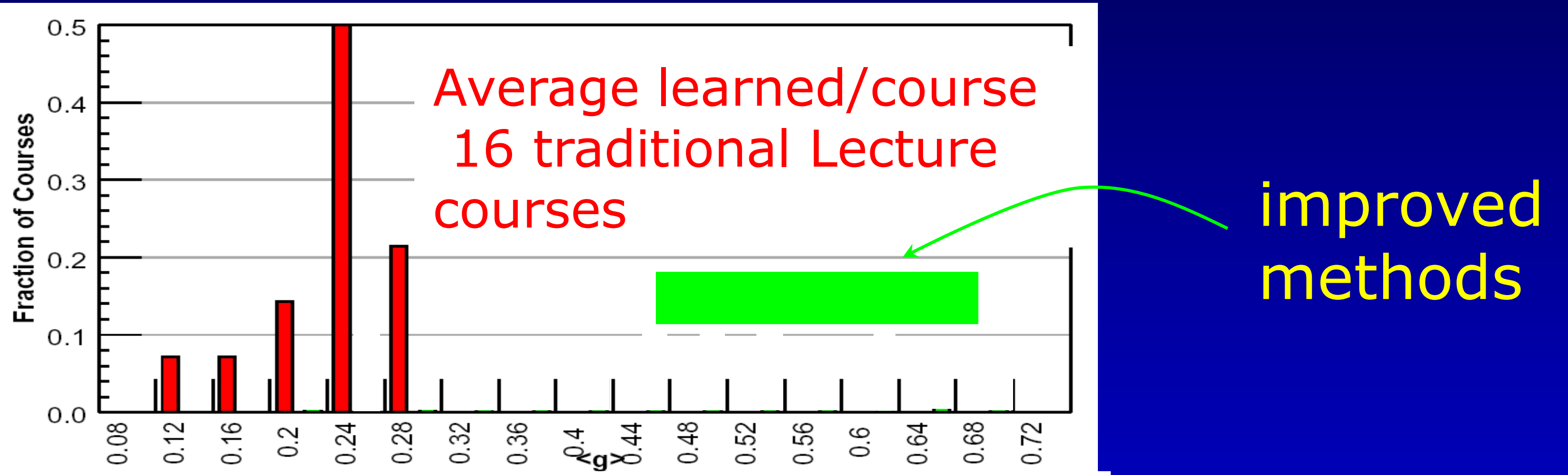
"How Scientists Think in the Real World: Implications for Science Education", K. Dunbar, Journal of Applied Developmental Psychology 21(1): 49–58 2000

Brief sampling of data on the results—
college science classrooms.

1. Measuring conceptual mastery

- basic concepts of force and motion
- "Force concept inventory" carefully developed test.

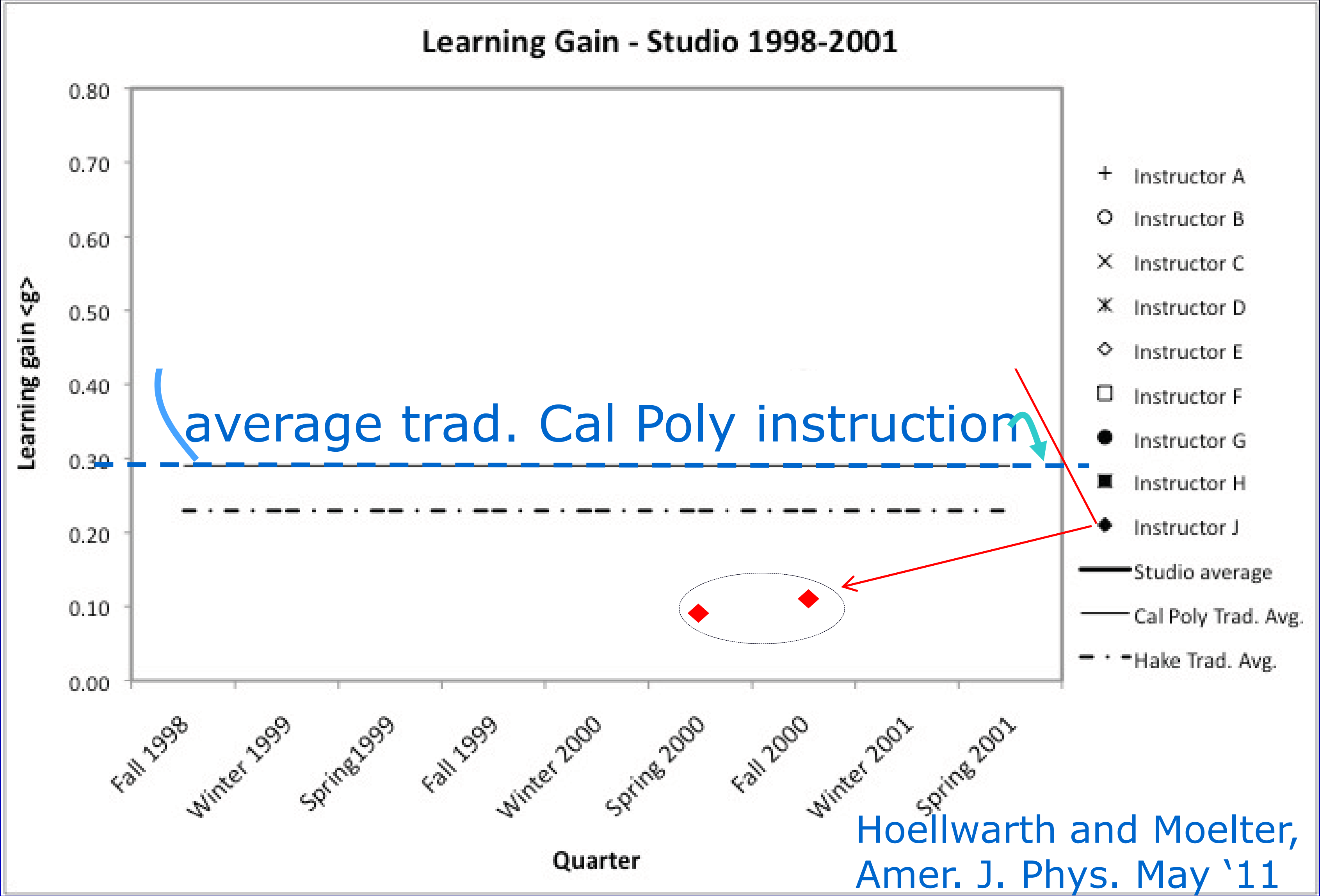
Ask at start and end of the semester--
What % learned? *(100's of courses/yr)*



Fraction of unknown basic concepts learned

On average learn <30% of concepts did not already know.
Lecturer quality, class size, institution,...doesn't matter!
Many similar examples.

R. Hake, "…A six-thousand-student survey…" AJP 66, 64-74 ('98).



2. Multiple instructors facilitating same established set of student activities.

Mental activities of the student dominates!

3. Good traditional teacher vs. research based practices*

- 2 ~identical groups of 270 regular students

- Same topics and learning objectives
- Same time (1 week), same test

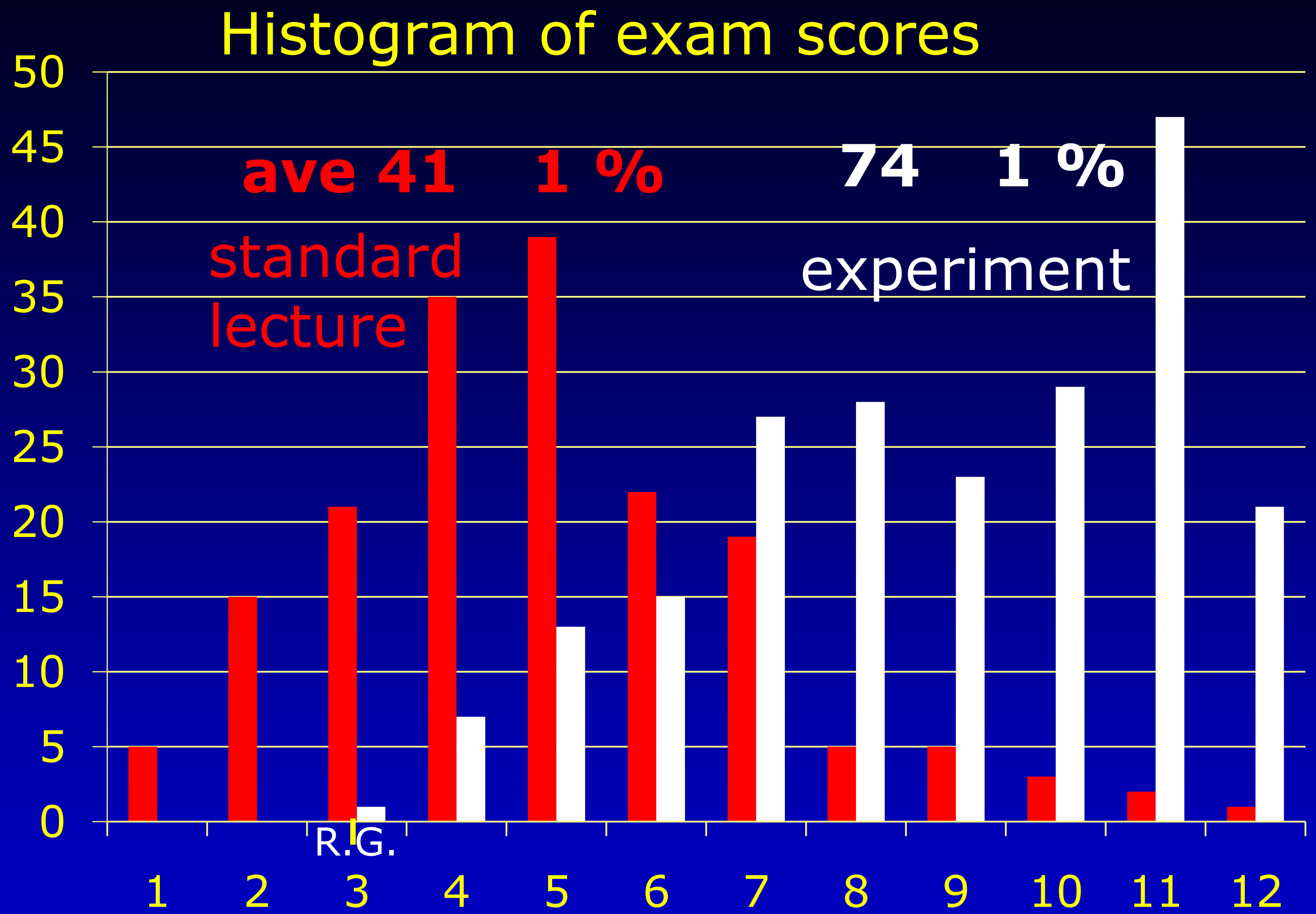
Very experienced, highly rated Prof--lecture

vs.

Inexperienced instructor trained in research-based teaching

*L. Deslauriers, E. Schelew, and C. Wieman

Science 13 May 2011: 862-864.



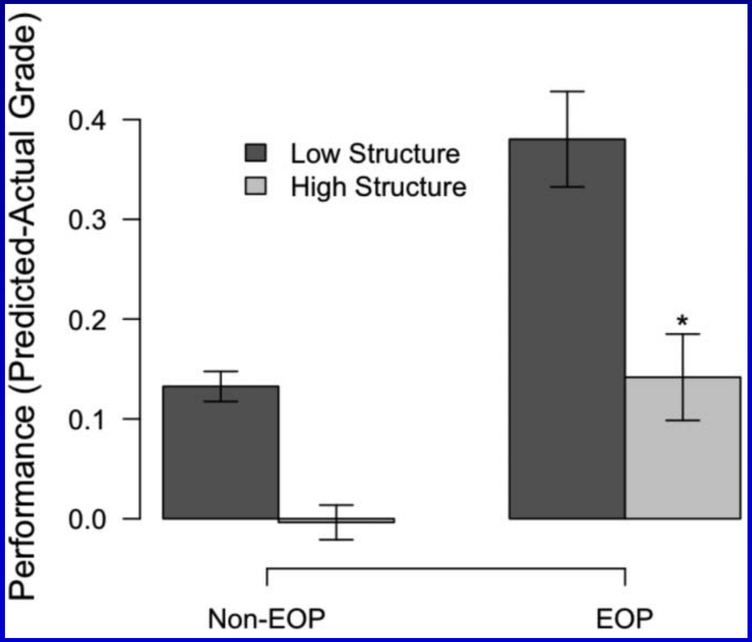
Clear improvement for <u>entire</u> student population

Results

	control	experiment
1. Attendance	53(3) %	**75(5)%**
2. **Engagement**	45(5) %	**85(5)%**

<u>4. Intro biology Univ. of Wash.– </u>similar research-based instruction

- All students improve
- Underrepresented students improve more
 (+1/3 letter grade)



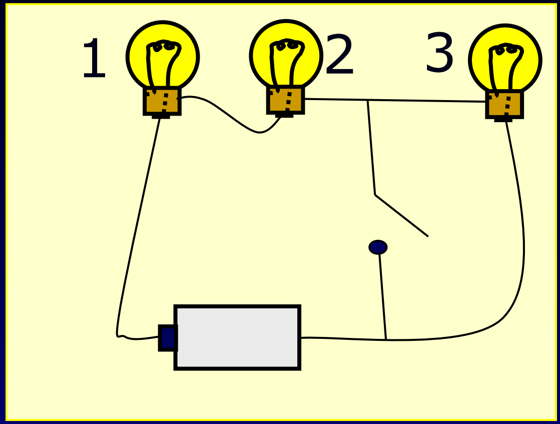
Science Magazine June 3, 2011 (Haak et al)

How does research-based teaching look in practice

Example from teaching about current & voltage--

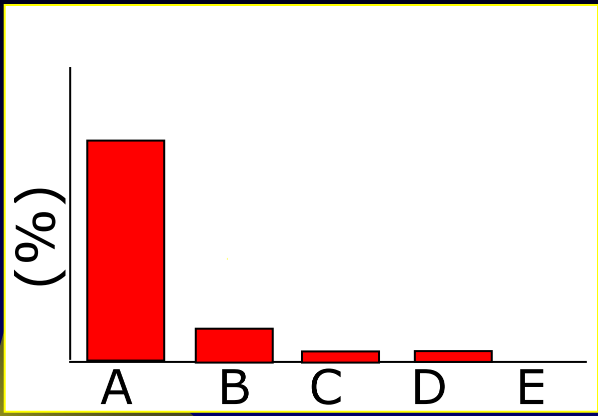
1. Preclass assignment--Read pages on electric current. Learn basic facts and terminology. Short online quiz to check/reward (and retain).

2. Class built around series of questions & tasks, minimal pre-prepared lecture.



When switch is closed, bulb 2 will

a. stay same brightness
b. get brighter
c. get dimmer,
d. go out.



3. Individual answer with clicker
(accountability, primed to learn)

4. Discuss with "consensus group", revote. (prof listen in!)
5. Elicit student reasoning, discuss. Show responses.
 Do "experiment."-- computer simulation. Many questions.

6. Variety of other small group tasks. (5-10 min)
"Explain why the light in a dorm room dims when an electric heater is plugged in. Include a diagram showing possible way(s) room may be wired."
"Write down on piece of paper with your name."

Instructor talking often, but **reactive--** responding to (many!) student questions. Guide thinking.

Requires much more subject expertise.

Reseach check list for an effective educational activity

apply to all levels, all settings

- ❑Connects with prior thinking?
- ❑Motivates to want to learn?
- ❑Not overload working memory?
  Facilitates long term retention?
- ❑Ensures practicing desired expert thinking?
- ❑Effective feedback provided?
- ❑Measures the learning that matters?

Summary:

Scientific approach to teaching ⇒ dramatic improvements in learning & success for all students.

Good Refs.:

NAS Press "How people learn"

Colvin, "Talent is over-rated"

Wieman, Change Magazine-Oct. 07
at *www.carnegiefoundation.org/change/*

cwsei.ubc.ca-- resources, references, effective clicker use booklet and videos

interactive simulations– free at phet.colorado.edu

Perceptions about science

Novice

Expert

Novice

Content: isolated pieces of information to be memorized.

Handed down by an authority. Unrelated to world.

Problem solving: pattern matching to memorized recipes.

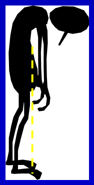
Expert

Content: coherent structure of concepts.

Describes nature, established by experiment.

Prob. Solving: Systematic concept-based strategies. Widely applicable.

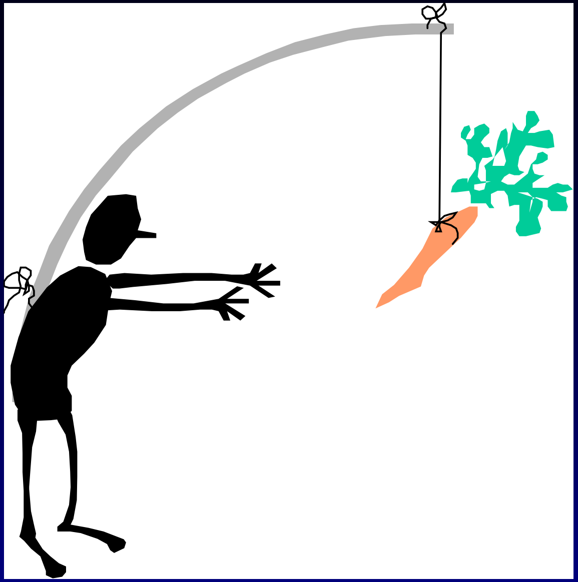
measure-- CLASS survey



intro physics course ⇒ *more* novice than before

chem. & bio as bad

*adapted from D. Hammer



<u>Motivation-- essential</u>

(complex- depends on previous experiences, ...)

Enhancing motivation to learn

a. Relevant/useful/interesting to learner (**meaningful context-- connect to what they know and value)**

b. Sense that can master subject and how to master

c. Sense of personal control/choice

Look at experts solving problem in their discipline—

Some Generic Components in STEM

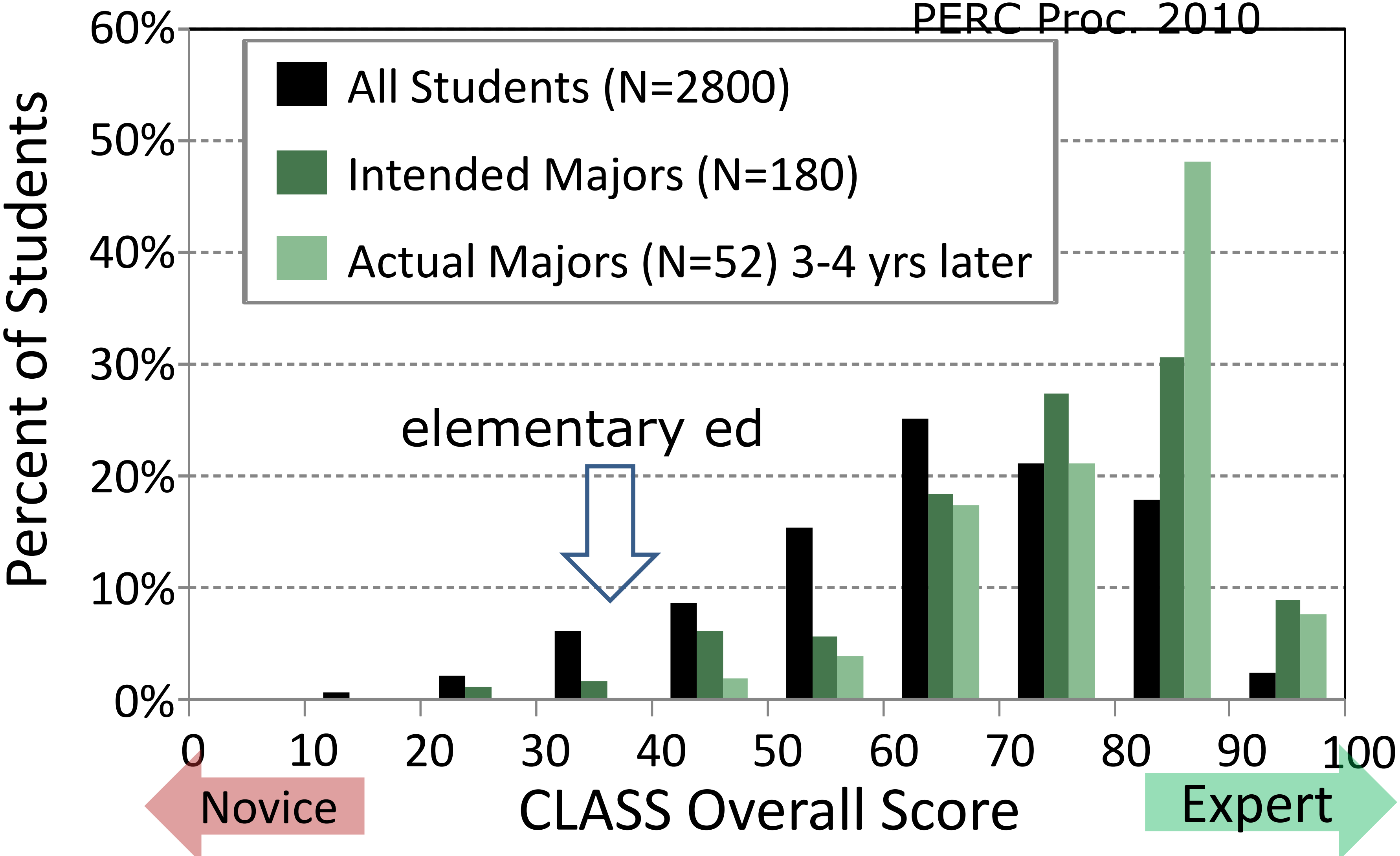
- concepts and mental models
- testing these and recognizing when apply
- distinguishing relevant & irrelevant information
- established criteria for checking suitability of solution method or final answer

(knowledge, but linked with process and context)

"How Scientists Think in the Real World: Implications for Science Education", K. Dunbar, Journal of Applied Developmental Psychology 21(1): 49–58 2000

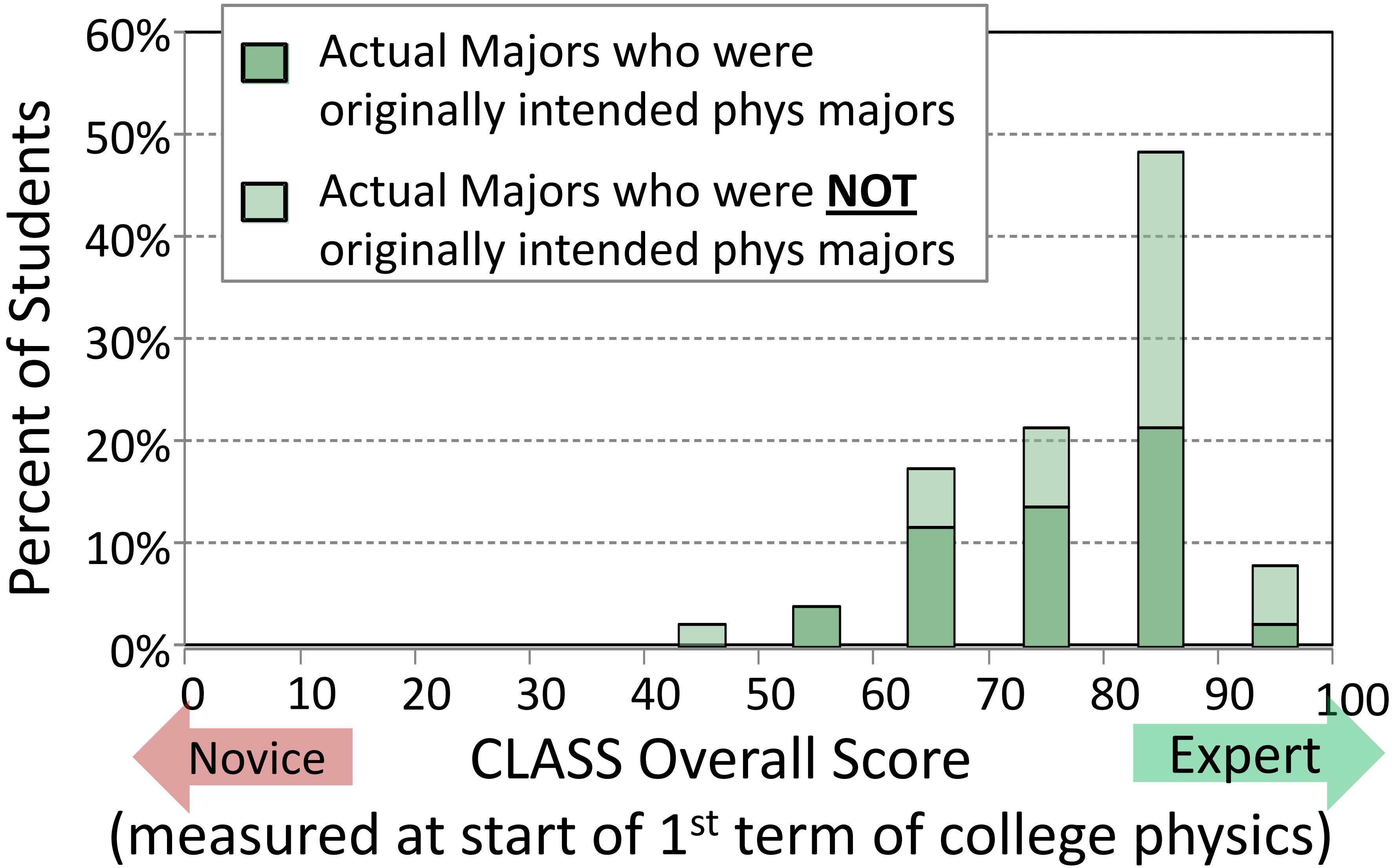
Student Perceptions/Beliefs

Kathy Perkins, M. Gratny
PERC Proc. 2010



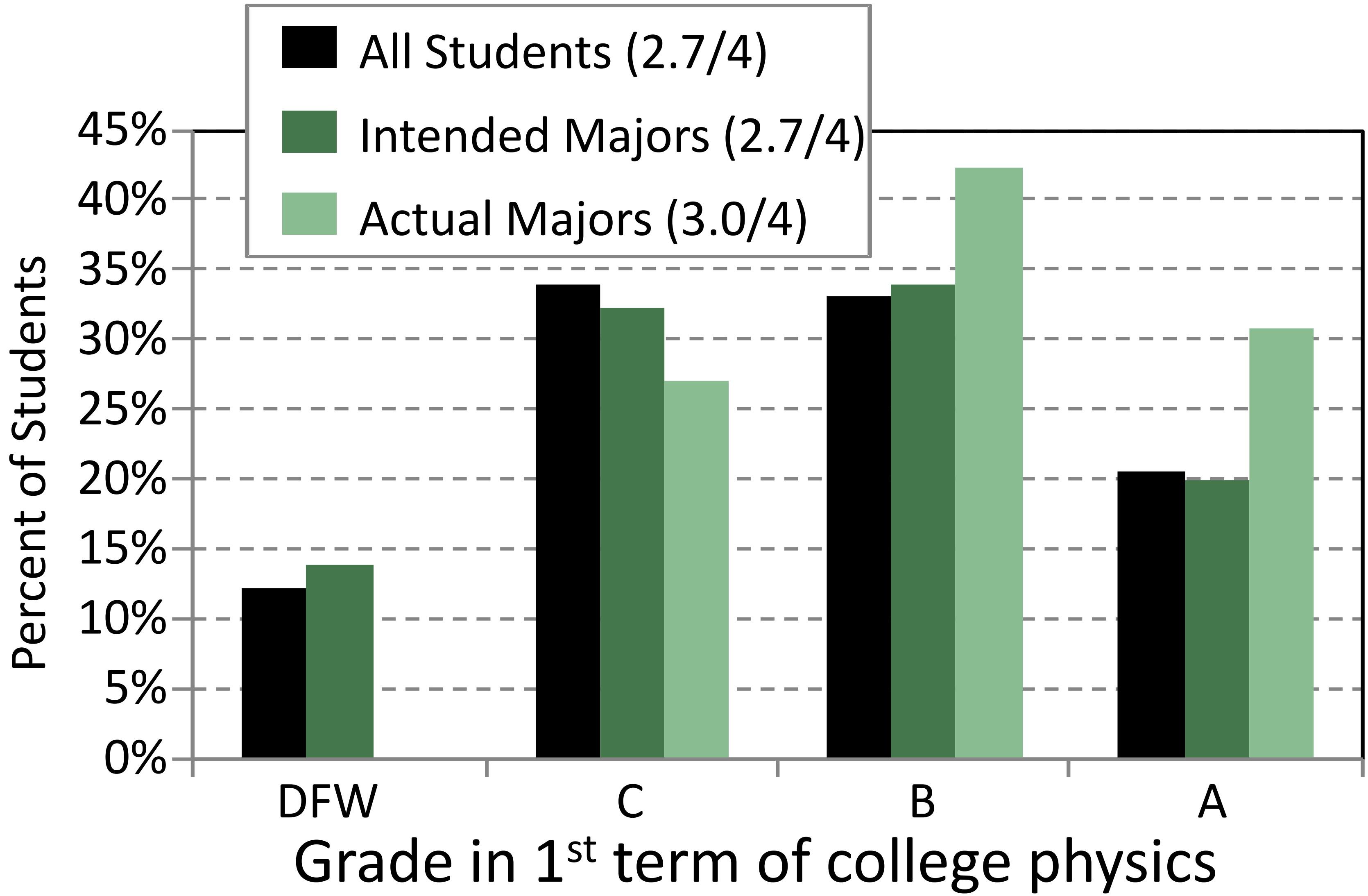
(measured at start of 1st term of college physics)

Student Beliefs



Course Grade in Phys I or Phys II

(day 1 beliefs more important than 1^{st} yr grades)



a. Limits on working memory--best established, most ignored result from cognitive science

Mr Anderson, May I be excused? My brain is full.

Working memory capacity **VERY LIMITED!** *(remember & process ~ 5 distinct new items)*

MUCH less than in typical lecture

slides to be provided

Two sections the same before experiment.
(different personalities, same teaching method)

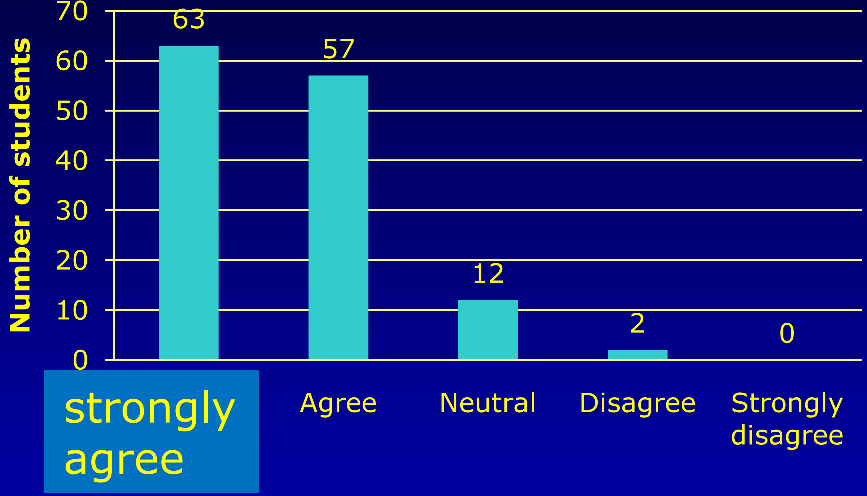
	Control Section	Experiment Section
Number of Students enrolled	267	271
Conceptual mastery(wk 10)	47± 1 %	47 ± 1%
Mean CLASS (start of term) (Agreement with physicist)	63±1%	65±1%
Mean Midterm 1 score	59± 1 %	59± 1 %
Mean Midterm 2 score	51± 1 %	53± 1 %
Attendance before	55±3%	57±2%
Engagement before	45±5 %	45±5 %

Results

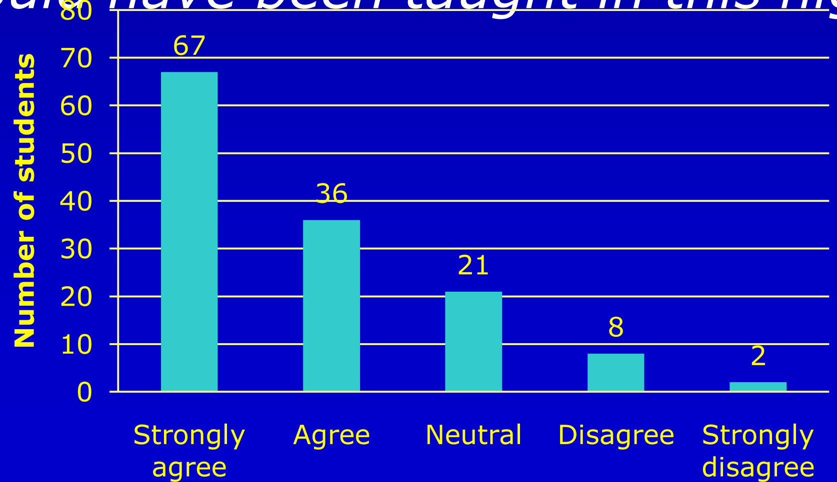
	control	experiment
1. Attendance	53(3) %	**75(5)%**
2. Engagement	45(5) %	**85(5)%**

Survey of student opinions-- transformed section

"Q1. I really enjoyed the interactive teaching technique during the three lectures on E&M waves."



"Q2 I feel I would have learned more if the whole phys153 course would have been taught in this highly interactive style."



Not unusual for SEI transformed courses